COMPARISON OF SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING AND SEASONAL VARIABILITY OF UPTAKE

by

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Recent laboratory techniques have refined detection limits and shed new information on soil and plant selenium (Se) levels within current mined land reclamation areas. The Wyoming Department of Environmental Quality Land Quality Division recommended procedures for soil Se determination include AB-DTPA and Hot Water Extractable analysis. Little information is available on the relationship of reclaimed area plant uptake on either of the recommended procedures. A three year study was initiated in 1991 to investigate the relationship of plant Se uptake and soil/backfill Se levels determined by five methods: Total, AB-DTPA, Hot Water Extractable, Saturated Paste Extract, and Potassium Phosphate. Soil and vegetation samples were collected in 1991 and 1992. "Spring" and "summer" sampling of vegetation was conducted in 1992 to determine any possible seasonal variability in Se uptake. Preliminary results of the 1991 and 1992 data indicate that the potassium phosphate extract is a significant indicator of plant level Se. Significant correlations existed between the plant Se values for 1991 and the two sampling periods in 1992. Results of the three year study will be ultimately used to help in determining overburden suitability limits for plant Se uptake.

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Introduction

Recent discussions of Se in various agronomic situations, i.e., Kesterson Irrigation Project in California and Kendrick Irrigation Project in Wyoming (Bainbridge, et al 1988, Bainbridge 1990, and See et al. 1992) have heightened the concerns of regulatory and industry personnel over possible consequences regarding large scale surface mining in seleniferous areas. Concerns include the possible production in reclaimed areas of vegetation greater than 5 ppm exchangeable Se. This concentration of Se may have toxic effects on rangeland grazing animals (National Academy of Sciences 1976).

The Powder River Basin coal region currently contains twenty-one active or proposed coal mines on a north-south trend within a 700 square mile area surrounding the towns of Gillette and Wright, Wyoming. Much of this mining is conducted within overburden areas that contain greater than 0.1 ppm Se, a soil level that may produce plant values greater than 5 ppm in native areas (Prodgers and Munshower, 1990).

Based on funding from the Abandoned Coal Mine Lands Research Program (ACMLRP), an intensive three year study was initiated in May, 1991 to determine the relationship between soil Se levels and plant uptake levels. Concurrent ACMLRP research at the University of Wyoming is being directed at different facets of the Se issue including the importance of solid and solution speciation of Se on mined lands, the role of organic solutes on the mobility of Se, and the toxicology of chronic selenosis in Wyoming.

The main objective of the three year study is to identify possible plant and soil Se relationships. Secondary objectives include: 1) identify laboratory analytical procedures that provide consistent, repeatable information; 2) identify possible Se forms that play a major role in the uptake of Se by plants; 3) identify other independent variables that may play a role in plant uptake of Se other than soil level Se and quantify those relationships with appropriate regression functions; 4) determine differences in Se uptake between species growing on either native or reclaimed areas; 5) determine the effect of soil depth on plant uptake of Se; and 6) recommend suitability limits for backfilled areas in the Powder River Basin of northeastern Wyoming.

This paper presents results of the 1991 and 1992 sampling program with an emphasis on summarized plant information. Soils information gathered in 1991 and 1992 will not be discussed in detail. Results presented are preliminary as final statistical regresssion analysis of the 1991 data has not been completed.

Methodology

Fieldwork was conducted on one abandoned mine site near Sheridan, Wyoming and two active mines south of Gillette, Wyoming, within the Powder River Basin coal region of northeastern Wyoming. The two active mines consist of one large mine (Mine L) and one small one (Mine S).

Full scale soil and vegetation sampling was conducted in 1991. A reduced, yet representative, subset of 1991 sample locations were resampled in 1992 for soil analysis. This reduced sampling was conducted to provide continuity in soils information over the three year study.

All twenty-three 1991 native area sample locations were sampled twice in 1992 for vegetation Se levels. Reclaimed area sampling locations were reduced from 87 in 1991 to 52 in 1992. This reduction allowed continuity in vegetation information over the three year study, while focusing on the overall purpose of Year 2, i.e., determine if there was a seasonal component in plant uptake of Se. Samples were collected during late May and early July, 1992. This paper includes only information from the two active mines; the abandoned mine information is not presented.

Soil and vegetation sampling was conducted on native and reclaimed areas within the two active mine permit areas. Sample locations were randomly chosen within native areas to represent all vegetation types present on the active mine permit areas. A total of 23 native (13 from Mine L and 10 from Mine S) and 87 (79 from Mine L and 8 from Mine S) reclaimed areas were sampled during 1991. Twenty-three native and 52 reclaimed area sites were sampled in 1992. Sample locations were placed among reclaimed areas ranging from 2 to 10 years old. Sample locations were marked with steel metal fence posts, which were located 25 feet south of the actual sample location, to prevent any deleterious effects from grazing animals.

During the soil sampling program of 1991, three holes were sampled using a triangular pattern with numbered holes (one through three) one meter apart; the center of the triangle was the actual sample location. This was conducted to provide information on the variability of Se data within a narrow area around each sample location. Corner 1 of the triangular area was randomly oriented to prevent bias that may result from a consistent compass direction orientation. Within native areas, soils were sampled by horizon to a maximum depth of 1.8 m. Within reclaimed areas, topsoil was sampled separately based on an approximate two foot replacement depth, and the underlying spoil was sampled at 0-0.6 m and 0.6-1.2 m. Soil data was summarized as a weighted average of horizon information for statistical analysis.

Based on the 1991 analysis of all three holes per sample location, variability between holes was generally low, based on the coefficient of variation for total selenium, and only one hole would require sampling during the 1992 subset sampling and 1993 full-scale resampling. For total Se, coefficients of variability ranged from approximately 17% on reclaimed areas to approximately 25% on native areas. Therefore, during 1992, a selected number of sample locations were resampled where 1991 Se values were high, medium, and low. All soil samples were sent to Intermountain Laboratories for processing and AB-DTPA, hot water extractable, and total Se analyses. The University of Wyoming provided the following data: pH, electrical conductivity, sulfates, saturated paste Se, and phosphate extract Se.

Full scale vegetation sampling was conducted at each of the 99 sample locations in 1991; a total of 110 were established but questionable vegetation analysis reduced the number of summarized sample locations to 99. A five to ten gram vegetation sample was collected within a 3.5 m radius from the center of the site. Sampled plants included the dominant four species based on a visual determination of relative site cover and a composite grass sample designed to simulate herbivore grazing. General plant cover was visually estimated using a system that grouped plants into the following gross cover percent categories: <1, 1-10, 11-25, 26-50, 51-75, 76-100.

Sampled vegetation was placed in pint size Ziploc storage bags, immediately placed on ice, and frozen within ten hours of collection. Samples were taken to the University of Wyoming and kept frozen until samples were dried at 50-60 degree Celsius for 24 hours in a forced air oven and then ground to 40 mesh using a Wiley plant grinder. Samples were then sent to Intermountain Laboratories in Sheridan, Wyoming, for total Se analysis.

Multiple regression analysis will be run on the data using SAS (SAS, 1990) on the University of Wyoming mainframe computer. Various combinations of independent and dependent variables will be analyzed to derive more appropriate and useable regression coefficients.

Results

In 1991, a total of 13 and 79 locations were sampled within native and reclaimed areas, respectively, at Mine L, while 10 and 8 were sampled at Mine S. In 1992, 13 and 46 locations were sampled within native and reclaimed areas, respectively, at Mine L, while 10 and 6 were sampled at Mine S. This translates to a total number of 1991 vegetation samples at Mine L of 389, not including those samples deleted for questionable analysis, and 100 at Mine S. May 1992 vegetation sample numbers were 278 at Mine L and 85 at Mine S. For the July 1992 vegetation sampling, a total of 251 plants were sampled at Mine L and 88 at Mine S. Within the 1992 sampling, 186 plant samples were common between the first and second sampling at Mine L, whereas 79 were common at Mine S. Wherever possible, four dominant species or lifeform categories and one composite grass were sampled at each location; however, the total number of plant samples per sample location varied slightly. Therefore, total number of plant samples available for statistical analysis varied slightly from original methodology.

Since some of the sample locations included primary Se indicator plants, some outlier points for total plant Se analysis are present within the data. To avoid skewing the data toward these obvious outliers, medians were calculated instead of means. Final analysis of the data will be conducted with these explainable, non-representative points deleted from the data set.

Within the 1991 sampling, median Se levels for all sampled vegetation species, including the composite grass sample, were 0.30 and 0.85 ppm within native areas and 0.65 and 0.50 ppm within reclaimed areas at Mine L and Mine S, respectively. No tests of significance were conducted on median determinations.

Within the May 1992 sampling, median Se levels for all sampled vegetation species, including the composite grass sample, were 0.85 and 0.90 ppm within native areas and 1.25 and 0.95 ppm within reclaimed areas at Mine L and Mine S, respectively. Within the July 1992 sampling, median Se levels for all sampled vegetation species, including the composite grass sample, were 0.65 and 2.70 ppm within native areas and 1.45 and 0.90 ppm within reclaimed areas at Mine L and Mine S, respectively. No tests of significance were conducted on median determinations.

The following vegetation species exceeded 5 ppm Se during 1991: *Astragalus bisulcatus* (2 individuals) within Mine L native area; *Agropyron smithii* (1), *Atriplex* *canescens* (2), and *Onobrychis viciaifolia* (1) within Mine L reclaimed area; *Agropyron dasystachyum* (1), *Koeleria macrantha* (1), *Vicia americana* (1), *Xylorhiza glabriuscula* (1), and *Gutierrezia sarothrae* (2) within Mine S native area; and *Bromus inermis* (1), *Taraxacum officinale* (1), and *Astragalus bisulcatus* (1) within Mine S reclaimed area.

- High soil Se levels were not always present at those sample locations that produced vegetation, accumulating and non-accumulating species, in excess of five ppm Se. In general, Se accumulator species have the potential to uptake Se independent of soil Se levels. Two areas at Mine L native areas and one at a Mine S reclaimed area, all containing high plant levels within *Astragalus bisulcatus*, showed extractable Se levels of <0.02 ppm in most depths for both hot water soluble and AB-DTPA Se. One native area at the smaller mine showing consistently high vegetation Se levels for all lifeform categories had extractable soil Se levels in excess of 0.30 ppm at depths greater than 0.3 m for both hot water soluble and AB-DTPA. The few high plant Se values on reclaimed areas at Mine L generally reflected high extractable soil Se values at depths of greater than 0.6 m.

Plant Se levels varied both between years and seasons. In general, median Se levels were higher in the 1992 sampling periods within both reclaimed and native areas. In 1992, 79% of all individual vegetation samples within the first sampling period were highest within the native areas at Mine L. At the same mine within the reclaimed areas, 56% of all individual vegetation samples within the second sampling period were highest. In 1992, 89% of all individual vegetation samples within the second sampling period were highest between the two periods within the native areas at Mine S. At the same mine within the reclaimed areas, 57% of all individual vegetation samples within the second sampling period were highest.

Based on a specific review of individual plant species within native areas, total Se was generally lowest in 1991 and, between the two 1992 sampling periods, was highest in the first sampling period (Table 1). Based on a specific review of individual species within reclaimed areas at Mine L, total plant Se displayed similar results found within native areas (Table 1). Information from Mine S was limited, and results for the listed species were varied (Table 1). These results may be highly species specific and combined results of all vegetation samples should be summarized for any possible conclusions. These results are only presented to provide some information on the variability between years and between sampling seasons within the same year.

Simple correlation coefficients were determined on the 1991 soil extractable and total Se concentrations and total Se versus the 1991 plant Se concentration of each lifeform category (i.e., grass, forb, and shrub) and the composite grass sample, based on an overall average. A brief summary of correlation coefficients for the three lifeform categories is presented in Table 2. Coefficients ranged from the low thirties to the mid seventies at p values ranging from 0.03 to 0.13.

Discussion

Current results on the possible relationship between soil Se and plant Se uptake are preliminary since final statistical analysis has not been conducted. Necessary independent variables to characterize plant Se, such as age of the reclaimed area or precipitation amounts, were not included in the early statistical analysis.

One of the preliminary findings evident from Table 1 is the importance of seasonality on collecting vegetation data within a given year and overall weather conditions between years. Weather within the Powder River Basin during 1991 was unusually cool and wet during April and May and extended to the end of June. During 1992, April and May were above normal for temperature and provided little or no precipitation while June and July were below normal for temperature and above for precipitation. In many respects, the spring and summer sampling periods were practically reversed during 1992 despite the calendar months.

For both Mine L and S, plant and soil extractable Se values were generally higher on reclaimed areas than native areas. Mine S contained overall higher selenium values for both native and reclaimed areas; therefore, selenium potential within both native and reclaimed areas may be site specific within the Powder River Basin itself.

The forb lifeform category was highest at Mine L native and was likely due to the inclusion of two-grooved milkvetch in the samples. The shrub lifeform category was highest at Mine S and may have resulted from more shrubs being encountered on Mine S reclaimed area.

Correlation coefficients for the various lifeform categories in Table 2 indicate significant correlations for AB-DTPA Extractable Se and HWS Se and various vegetation lifeforms existed in Native-Grass, Native-Shrub, and Reclaimed-Shrub, regardless of mine. If mine were specified, it is anticipated that correlation coefficients would be higher and significant differences would exist between Mine L and Mine S. Only AB-DTPA and HWS correlation coefficients were included in Table 2 since these are the two current Wyoming state recommended soil extractable Se procedures.

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Table 1. Selected Plant Species[1] Summary of Total Selenium Range, Mean, and Standard Deviation.

Sampled Area[2]	Plant Species	Total # Plots	Total Plots w/Plant #	%	Range of Values	Mean ± 1 S.D.	Sampling Date 1991[3]	1992-1[4]	1992-2[5]
L-R	Agrsmi	71	45	63.4	0.05-5.00	1.15 ± 1.28	X		
	Agrsmi	46	38	82.6	0.15-4.30	1.42 ± 1.04		X	
	Agrsmi	46	43	93.5	0.30-5.15	1.74 ± 1.14			X
	Medsat	71	49	69.0	<.01-2.50	0.78 ± 0.64	X		
	Medsat	46	32	69.6	0.20-8.05	1.76 ± 1.59		X	
	Medsat	46	34	73.9	0.40-6.70	2.07 ± 1.71			X
	Atrcan	71	15	21.1	<.01-21.25	4.06 ± 5.60	X		
	Atrcan	46	18	39.1	0.95-23.00	5.55 ± 4.75		X	
	Atrcan	46	23	50.0	0.40-38.00	7.63 ± 9.08			X
S-R	Agrsmi	8	8	100.0	<.10-3.80	0.97 ± 1.34	X		
	Agrsmi	6	6	100.0	0.20-7.65	2.06 ± 2.91		X	
	Agrsmi	6	6	100.0	0.30-5.15	1.74 ± 1.71			X
	Ratcol[6]	8	2	25.0	0.15-0.50	0.33 ± 0.25	X		
	Medsat	6	1	16.7	0.40	-		X	
	Medsat	6	1	16.7	0.65	-			X
	Atrcan	0	0	-	-	-	X		
	Atrcan	6	1	16.7	1.45	-		X	
	Atrcan	6	1	16.7	3.40	-			X
L-N	Agrsmi	10	3	30.0	0.25-0.65	0.42 ± 0.21	X		
	Agrsmi	13	6	46.2	0.20-1.05	0.83 ± 0.33		X	
	Agrsmi	13	6	46.2	0.40-1.35	0.77 ± 0.36			X
	Astbis	10	2	20.0	34.00-37.00	35.5 ± 2.12	X		
	Astbis	13	2	15.4	91.00-170.50	131 ± 56.22		X	
	Astbis	13	2	15.4	25.00-115.29	70 ± 63.84			X
	Arttri	10	5	50.0	0.20-0.50	0.36 ± 0.11	X		
	Arttri	13	7	53.9	0.05-1.9	0.71 ± 0.59		X	
	Arttri	13	6	46.2	0.40-2.10	0.78 ± 0.66			X

Table 1. Selected Plant Species[1] Summary of Total Selenium Range, Mean, and Standard Deviation. (cont.)

Sampled Area[2]	Plant Species	Total # Plots	Total Plots w/Plant #	Total Plots w/Plant %	Range of Values	Mean ± 1 S.D.	Sampling Date 1991[3]	Sampling Date 1992-1[4]	Sampling Date 1992-2[5]
S-N	Agrsmi	10	6	60.0	0.25-3.10	1.30 ± 1.00	X		
	Agrsmi	10	6	60.0	0.50-6.05	2.11 ± 2.04		X	
	Agrsmi	10	6	60.0	1.60-4.70	3.21 ± 1.32			X
	Gaucoc	10	1	10.0	1.00	-	X		
	Gaucoc	10	1	10.0	3.75	-		X	
	Gaucoc	10	0	-	-	-			X
	Artfri	10	3	30.0	0.60-0.90	0.75 ± 0.15	X		
	Artfri	10	4	40.0	0.70-1.80	1.18 ± 0.49		X	
	Artfri	10	4	40.0	1.15-2.40	1.86 ± 0.61			X

[1] Plant species selection based on presence over the three sampling periods and relative abundance within reclaimed or native areas.
[2] First letter designates mine; second letter designates reclaimed or native.
[3] Collected in June, 1991.
[4] Collected in May, 1992.
[5] Collected in July, 1992.
[6] Not collected in 1992.

Table 2. Vegetation Lifeform/Soil Se Correlation Coefficient Summary for Total Se, AB-DTPA and HWS Extractable Se.

Sampled Area	Lifeform Category[1]	Depth[2]	Total Soil Se	AB-DTPA Extracted Soil Se	HWS[3] Extracted Soil Se
Native	Grass	1	N.S.[4]	N.S.[4]	N.S.[4]
		2	0.44	0.75	0.77
		3	0.36[5]	0.74	0.50
		4	N.S.[4]	0.65	0.72
		5	N.S.[4]	0.60	0.66
Reclaimed	Grass	1	0.53	N.S.[4]	N.S.[4]
		2	0.73	N.S.[4]	0.59
		3	0.70	0.35[5]	0.60
Native	Forb	1	0.30[5]	N.S.[4]	N.S.[4]
		2	N.S.[4]	N.S.[4]	N.S.[4]
		3	N.S.[4]	N.S.[4]	N.S.[4]
		4	0.36[5]	N.S.[4]	N.S.[4]
		5	0.35[5]	N.S.[4]	N.S.[4]
Reclaimed	Forb	1	0.56	N.S.[4]	0.54
		2	N.S.[4]	N.S.[4]	N.S.[4]
		3	N.S.[4]	N.S.[4]	N.S.[4]
Native	Shrub	1	N.S.[4]	N.S.[4]	N.S.[4]
		2	N.S.[4]	0.57	0.58
		3	N.S.[4]	0.61	0.35[5]
		4	N.S.[4]	0.58	0.67
		5	N.S.[4]	0.48	0.53
Reclaimed	Shrub	1	0.42[5]	N.S.[4]	N.S.[4]
		2	0.56	0.61	0.53
		3	0.66	0.63	0.57

[1]Average of all individuals, except grass which includes composites.
[2]Native Depths:
1 - 0 to 0.3 m
2 - 0.3 to 0.6 m
3 - 0.6 to 0.9 m
4 - 0.9 to 1.2 m
5 - 1.2 to 1.5 m

Reclaimed Depths:
1 - replaced topsoil
2 - 0 to 0.6 m of regraded backfill
3 - 0.6 to 1.2 m of regraded backfill

[3]Hot water soluble.
[4]N.S. = Not Significant
[5]Signifies correlation at the 0.05 level, all others at 0.01.

NOTE: AB-DTPA and HWS two Wyoming recommended procedures for extractable Se.

CHARACTERIZATION OF SUBSIDENCE LAND RECLAIMED BY HYDRAULIC DREDGE PUMP IN CHINESE COAL MINES[1]

by

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Abstract With the excavation of coal from underground, the severe subsidence often results, which causes huge losses of cultivatable lands. In China, a simple but practical reclamation technique ---- Hydraulic Dredge Pump (HDP) is being used in subsidence land reclamation. But the characteristics of reclaimed land by this sort of technique has not been studied so far. This research was conducted on two field plots to ascertain whether soil amelioration treatments are necessary in the reclaimed land. Plot I was reclaimed land by using of the HDP method, Plot II was adjacent undamaged farmland. The main soil physical and chemical properties were tested for comparison between the two plots. The result showed that this sort of reclaimed land was reconstructed land which had higher clay content. Its surface was hardened and impervious. Cracks was found in the land. Moisture content of the reclaimed land was very high, which was about 1.5 to 2.5 times as much as that of farmland. The infiltration was much slower than that of farmland. But the bulk densities of the two plots were not tremendously different. The soil fertility analysis proved that the reclaimed land was poorer than that of farmland. Therefore, the soil amelioration treatments of the reclaimed land are needed for achieving reclamation success. Also, the reclamation process of the HDP technique was introduced in this paper.

Additional key words: soils, subsidence, reclamation technique, hydraulic dredge pump, soil properties, wetlands, underground coal mine

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Introduction

In China, 96% of the coal is produced by underground mines. The underground coal mining has caused a large amount of lands to subside, which has led to farmland losses and caused severe conflicts between farming and mining. According to statistics, the subsidence lands due to coal mining are more than 13,300 hectares each year. Half of this acreage is located in the plain area, which consits of prime farmlands (Sun and Li 1990). This situation makes the subsidence land reclamation become an urgent task for our country.

The HDP is a set of machines for earthwork, which includes a high-pressure pump, hydraulic giants (water syringes), a slurry pump, two electric machines, two float bowls, some steel and plastic pipes, etc. It is widely used in excavating fish ponds, dredging rivers or irrigation ditches, building river banks, etc. The basic principle of the reclamation method is that using the HDP machine, simulating the natural water erosion and turning the mechanical and electrical power into hydraulic power for digging, transporting and filling of soils (see Figure 1). The procedures are: (1) excavating soils by use of hydraulic giants with high-pressure and high speed water produced by high pressure pump, which makes the soils become slurry; (2) transporting the slurry to the subsidence trough to be filled through transportation pipes by use of the slurry pump; (3) leveling the reclaimed land by manual work or dozers. This method has many advantages such as: the equipment is simple, the cost is low, the operation efficiency is high and the operation is convenient and not affected by weather.

In the comprehensive treatments for subsidence lands due to coal mining, the method of reclaiming lands by Hydraulic Dredge Pump (HDP) called "digging deep to fill shallow" is being used in our country. This reclamation method destroys the original soil profile and results in the formation of a new rooting medium. The characteristics of land reclaimed by this technique have not been studied. This study characterized the reconstruct soils reclaimed by HDP so that the improving treatments for the new soil and the HDP method could be found.

Material and Methods

The experiment site is in the subsidence area of the 8th mine of Pingdingshan coal mine bureau, Pingdingshan, Henan province. The subsidence lands were about 31.3 hectares. Among these damaged land, 14.1 hectares were filled by water because of the high ground water level. The maximum subsidence depth was about 2.3m. At the end of October 1991, about 6.7 hectares of land were reclaimed by HDP method. No other treatments were done on the reclaimed lands. Soil samples were taken in April, 1992. And an adjacent undamaged farmland with wheat was also chosen for comparison.

The soil condition reclaimed by HDP will directly affect the reclamation effectiveness. This study described following properties of the reclaimed soil: (1) soil profile, (2) soil bulk density (3) soil porosity, (4) moisture content, (5) infiltration, (6) organic matter and some macronutrient contents.

Results and Discussion

Soil profile characterization

The excavated soil pits revealed that the reclaimed soil lacked topsoil and distinct horizontal layers. Instead, the reclaimed soil was a mixture of original topsoil and subsoil from adjacent area. It was easy to recognize that clay and moisture contents were very high, and the surface was the hardened and imperious soil. The thickness of the reclaimed soil was about 60-85cm. Underlying the reclaimed soil was the original soil profile. Undamaged farmland had an average of 15cm of topsoil and distinct horizontal layers. The upper layer of the farmland soil was darker than the underlying layers as well as the reclaimed soil because of the accumulation of organic matter. The granular structure dominated the topsoil of farmland, while the platy and subangular blocky structure were noted in the reclaimed soil.

Soil bulk density and soil porosity

Table 1 shows the average bulk density and porosity of sampled soils. Due to the high clay contents of the reclaimed soil, the top soil was easy to be hardened. Thus, the bulk density at the depth of 0-20cm was larger than that of undamaged soil, and the porosity at the same depth was lower than that of undamaged soil. The underlying soil on reclaimed sites had similar bulk density and porosity to the undamaged soil. The values of bulk density and porosity of the reclaimed soil were not extreme enough to severely restrict plant growth.

Soil moisture content

The soil moisture content is the important factor affecting the plant growth. Numerous other soil properties depend very strongly upon moisture content (Hillel 1982). The results listed in table 1 showed that the moisture content of the reclaimed soil was very high, which was about 1.5 to 2.5 times as much as that of farmland. Thus, the moisture content was the main factor restricting plant growth in the reclaimed soil. The high moisture content mainly came from the high clay content of the soil and the HDP method itself. Therefore, the drainage for the superfluous water in the reclaimed soil is the key to making the reclamation successful. And, the establishment of drainage system should be one of procedures of the HDP operation.

Infiltration

As the reclaimed soil had high moisture content and clay content, the infiltration should be lower than that of farmland. The tested results by single ring method (see Figure 2) revealed that the infiltration rate at the one hour point of the farmland was about 6 times as much as that of the reclaimed soil, which were 0.0033cm/sec and 0.0006 cm/sec respectively. The result might lead to the severe erosion and nutrient losses in the reclaimed soil.

Organic matter and other nutrients

The Organic Matter content (OM) is one of the important fertility factors. Reclaimed soil had much lower organic matter content than farmland soils (see Figure 3). The distribution of organic matter content along the vertical soil profile was also different between the two kinds of lands: the upper layer (0-20cm) of the farmland soil had higher OM content than the underlying layer (20-40cm), which is the typical characteristics of agricultural soil; but in the reclaimed soil the upper layer (0-20cm) had similar OM content to the underlying layer (20-40cm), some time the upper layer had lower OM content than the underlying layer. The difference in the distribution of OM content revealed that the HDP reclamation method led to the mixture of original soil layers, and some time the original underlying layer was covered on the the original upper layer. Therefore, the poor characteristics was produced by the HDP method itself. Some improvements for the HDP method are needed.

Soil nutrient levels for the soil samples as shown in table 2. The reclaimed soil had quite lower contents of total nitrogen, total phosphorous and rapidly available nitrogen than the farmland soil. The contents of rapidly available phosphorous and potassium of the reclaimed soil were also lower than that of the farmland soil. Thus the reclaimed soil had much lower comprehensive fertility than that of farmland soil. The amelioration treatments of the reclaimed soil are necessary.

Conclusion

Based on the findings of this research, the following conclusions can be made.

1. The soil profile examination showed that the reclaimed soil by use of HDP resulted in a massive structure soil, which was the mixture of original topsoil and subsoil, and had high clay content and no district horizontal layers.
2. The analysis of soil physical properties of the reclaimed soil indicated that the bulk density and porosity were nearly ideal for plant growth. However, the moisture characteristics of the reclaimed soil was the most severe factor restricting plant growth because of the high moisture content (almost close to saturate) and slow infiltration. Therefore, the establishment of drainage system is the key to making the reclamation successful and should be one of procedures of the HDP operation.
3. The soil fertility assessment indicated that the reclaimed soil was very poor, and the amelioration treatments are necessary.
4. Although the HDP reclamation technique is a practical method for subsidence land reclamation in China, it produces a very poor soil. Thus, the improvements of the technique itself are needed, especially the replacement of topsoil should be one of procedures of the HDP operation.

Reference

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Table 1. The results of soil bulk density, porosity and moisture content

type of soil	depth (cm) 0-20	20-40	40-60	60-80
	Bulk density (g/cm^3)			
undamaged	1.16	1.55	1.56	1.49
reclaimed	1.32	1.46	1.49	1.37
	Porosity (%)			
undamaged	56.2	41.5	41.1	43.8
reclaimed	50.2	44.9	43.8	48.3
	Moisture content (%)			
undamaged	13.8	14.0	15.5	14.3
reclaimed	26.3	35.5	38.4	31.3

Table 2. Some macronutrient contents

type of soil	depth (cm)	total N (%)	total P (%)	apidly available nutrients N (ppm)	P (ppm)	K (ppm)
farmland	0-20	0.107	0.167	87	14.1	112.5
	20-40	0.066	0.130	47	3.7	95
reclaimed	0-20	0.042	0.091	25	2.7	97.5
	20-40	0.042	0.098	27	1.4	95

Figurel. The reclamation operation by use of the hydraulic dredge pump in Chinese subsidence trough

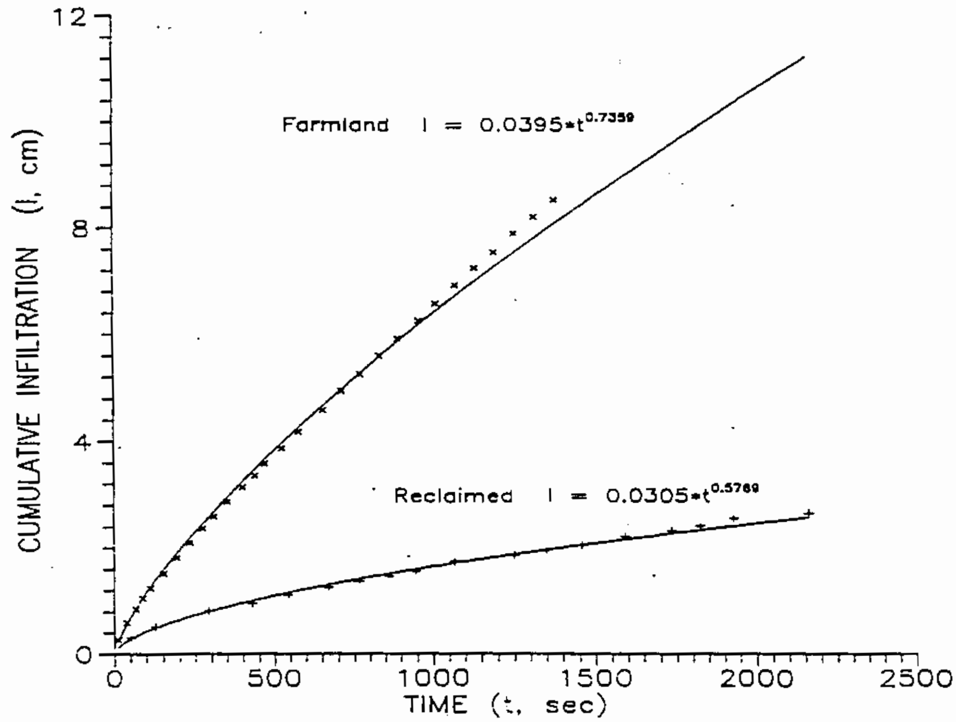

Figure 2. Comparison of infiltration between farmland soil and reclaimed soil

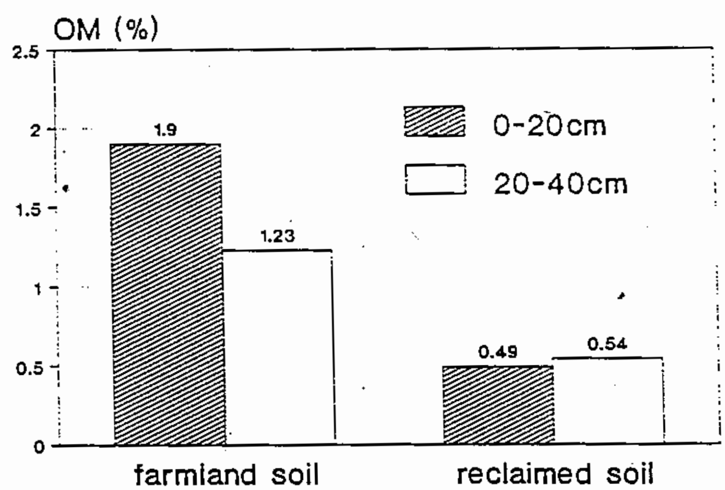

Figure 3. Organic matter content